



The EO-1 Autonomous Science Agent

June 23, 2004

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Outline



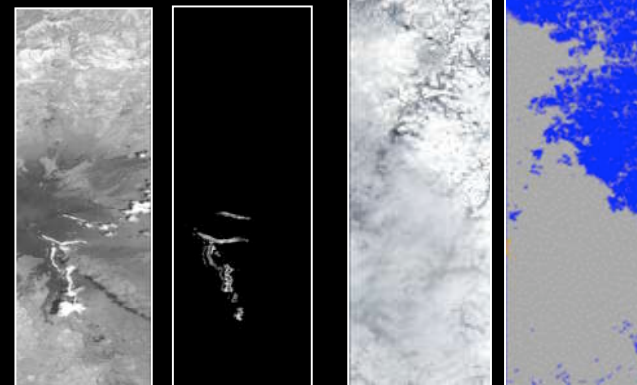
- Overview of Autonomous Science on EO-1
 - Rationale
 - EO-1 Mission
 - Software Technologies
 - Science
- Future Applications of Autonomous Science
- Extension to Sensorweb Experiments
- Summary/Conclusions



ASE Autonomy Software

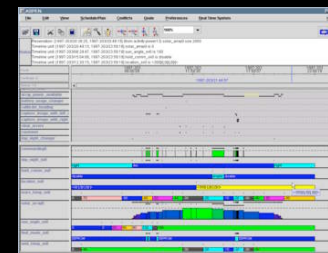
Autonomous Science

- Volcanic activity detection via spectral analysis (lava detection)
- Atmospheric feature (cloud) detection used for onboard data editing
- Feature detection via spectral analysis (land-ice-water-snow)



Autonomous Planning (CASPER)

- CASPER enables onboard development of new plans in response to science events
- CASPER generated plans respect EO1 resource and flight constraints



Autonomous Execution Software (Spacecraft Command Language)

- SCL expands CASPER plans into spacecraft commands
- SCL enables robust plans to deal with run-time uncertainties



ASE Scenario

JPL





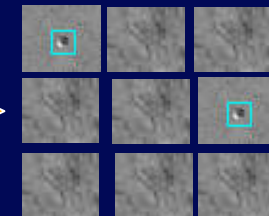
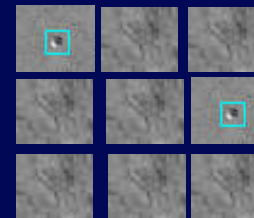
Why fly autonomy software onboard?

- To utilize limited downlink resource
- To capture dynamic science



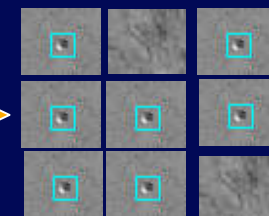
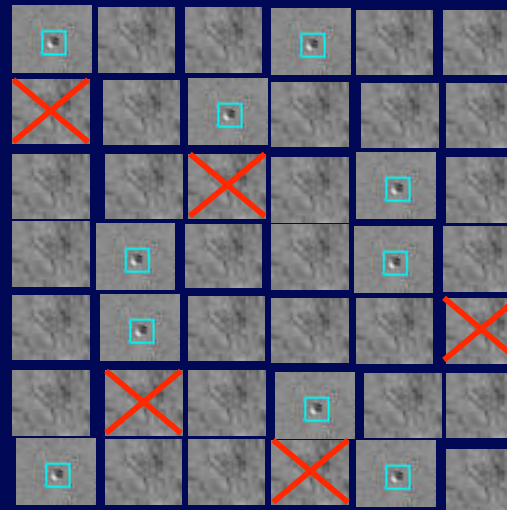
Old Way:

- Take 200 Images
- Downlink 200 images



New Way:

- Take 2000 Images
- Downlink best 200 images
 - Only most scientifically interesting portions
 - Could be cloud free images





Technology Carrier: EO1 Mission

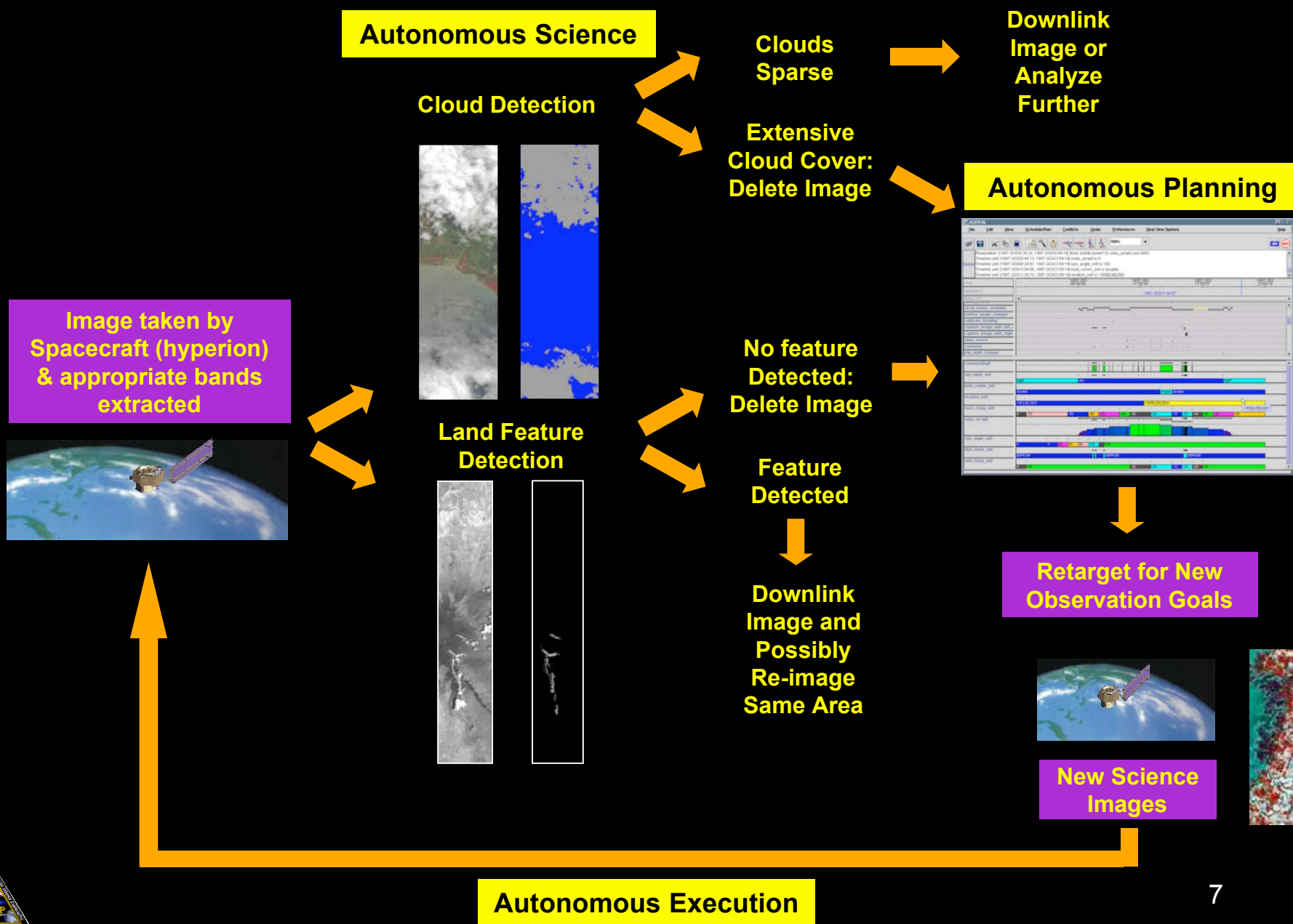
JPL

- ASE is a technology experiment
 - Part of New Millennium ST6 Project
 - Subsystem demonstration
 - Funded to flight demonstrate autonomy software technology for future mission adoption
 - Uses Hyperion instrument (hyper-spectral, 220 bands, 30 m resolution)
- CDS: Two Mongoose V CPU's
 - Mongoose V @ 8 MIPS and 256 MB RAM
 - Flight control software on CDH CPU
 - Autonomy software on instrument CPU





ASE on EO1 Mission Scenario





Autonomous Science

- Utilize onboard science analysis to summarize, retarget, or rapidly respond to science events to increase science return
- Onboard Science Components
 - Cloud detection
 - Thermal anomaly detection
 - Land, Ice, Water, Snow, Vegetation Recognition
 - Change detection
 - Feature recognition software (looking for specific patterns)
- Algorithms are valid for multiple features and processes: we are not limited to specific types of science targets
- The science analysis algorithms can be used for several imaging datasets (visible, IR, UV, radar, etc.) although we are taking advantage of the multi-spectral capabilities of Hyperion
- Onboard ASE Science Classifiers utilize up to 12 bands of L0.5 Hyperion data (including 6 used by cloud detection algorithm)



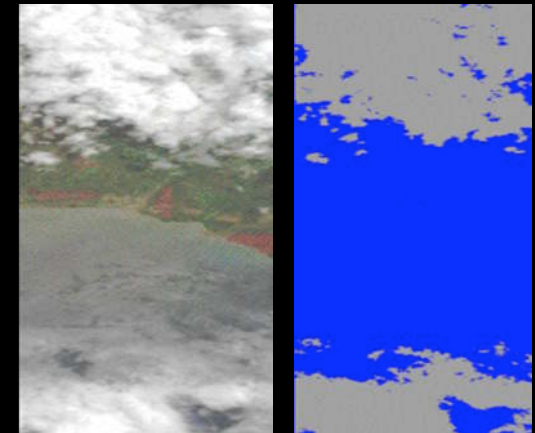


Cloud Detection & Thermal Anomaly Detection

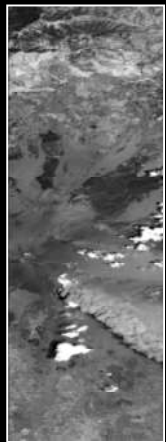


- **Cloud detection**

- Developed by MIT/Lincoln Labs
- Uses intensities at six different spectra and thresholds to identify likely clouds in scenes
- Leverages key spectra for high accuracy with simple approach
- Discard scenes that are mostly clouds
- Cloud detection algorithm good analogue for Space Science mission atmospheric feature applications (such as Mars dust storm detection)



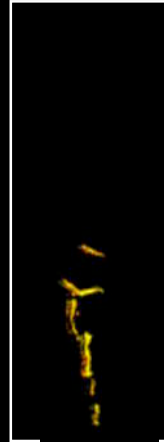
Original Image Detected Clouds



Visual Spectra



Infra-red Spectra



De ava

- **Thermal anomaly detection**

- Uses infrared spectra characteristics to detect lava flows & other volcanic activity
- Has been tested successfully on ground and in flight
- Good analogue for Space Science mission thermal anomaly detectors (such as Mars Odyssey & Io missions)



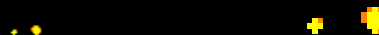
Active Volcanism Detection



VIS data

Erta'Ale, Ethiopia
14 May 2001

Main lava lake



Possible artifact:
may be second vent

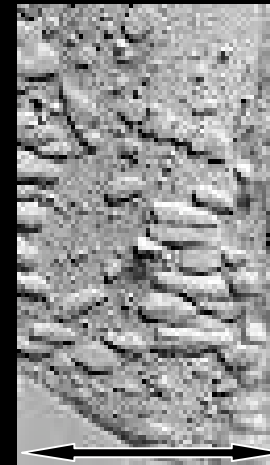
Thermal classifier output

- **Land-Ice-Water-Snow Detection**

- Developed at JPL
- Uses multiple spectra to identify areas of image with land, ice, water, and snow
- Observation process:
 - Classify pixels, count pixels of water-ice-snow-land
 - Compare with previous observation for new water or ice
 - If change is detected, trigger re-observation to monitor the rate of ice formation or break-up
 - Downlink entire new dataset

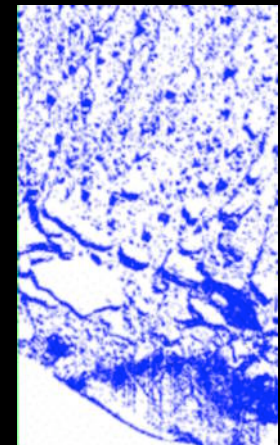
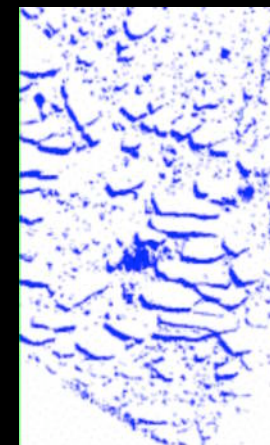
Location: Larsen Ice Shelf,
 Antarctica
 Process: Break-up of ice shelf
 Trigger: Change Detection
 Classifier Output:
 Water is blue, Ice is White

4/6/2002



7 km

4/13/2002





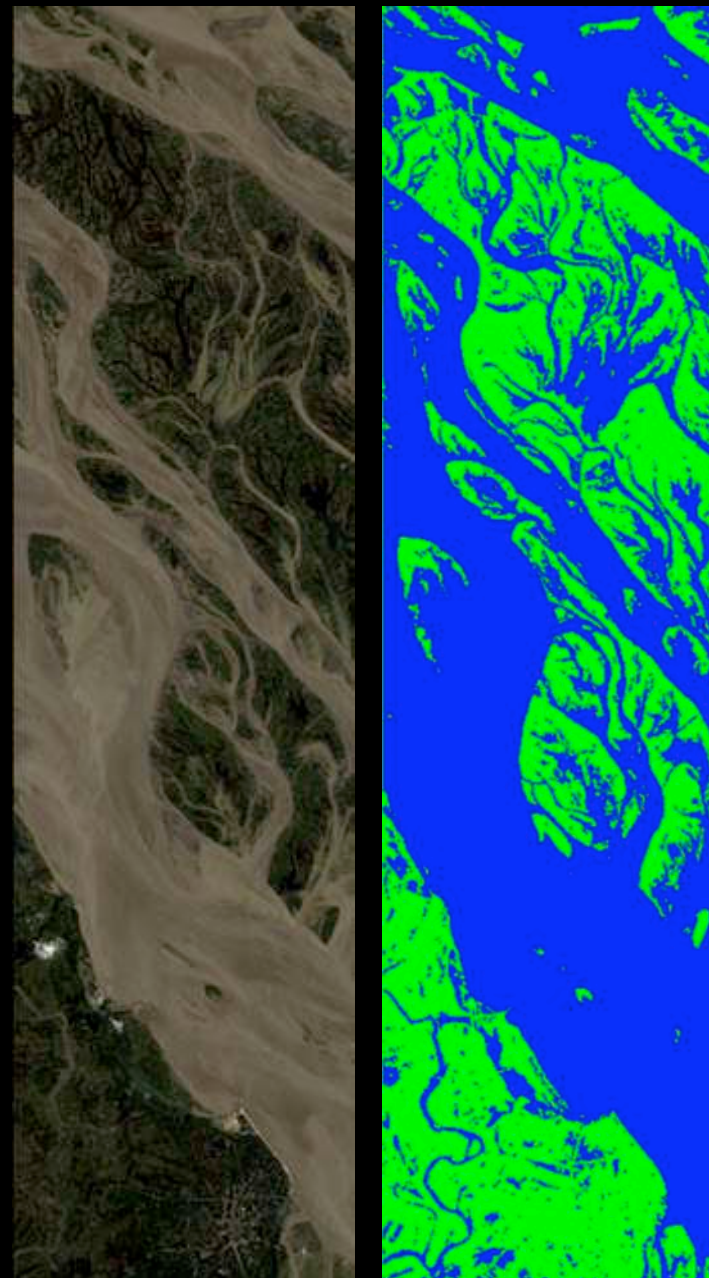
Flood Detection



- **Flood Detection**
 - To monitor regions that seasonally flood, demonstrating ASE change detection.
 - Observation process:
 - As with ice: classify observation and count water pixels as basis for comparison
 - If sufficient number of changed pixels (a large enough area of change detected), then download data and retask spacecraft to obtain more data

Brahmaputra River, India
Hyperion data, Aug 2003

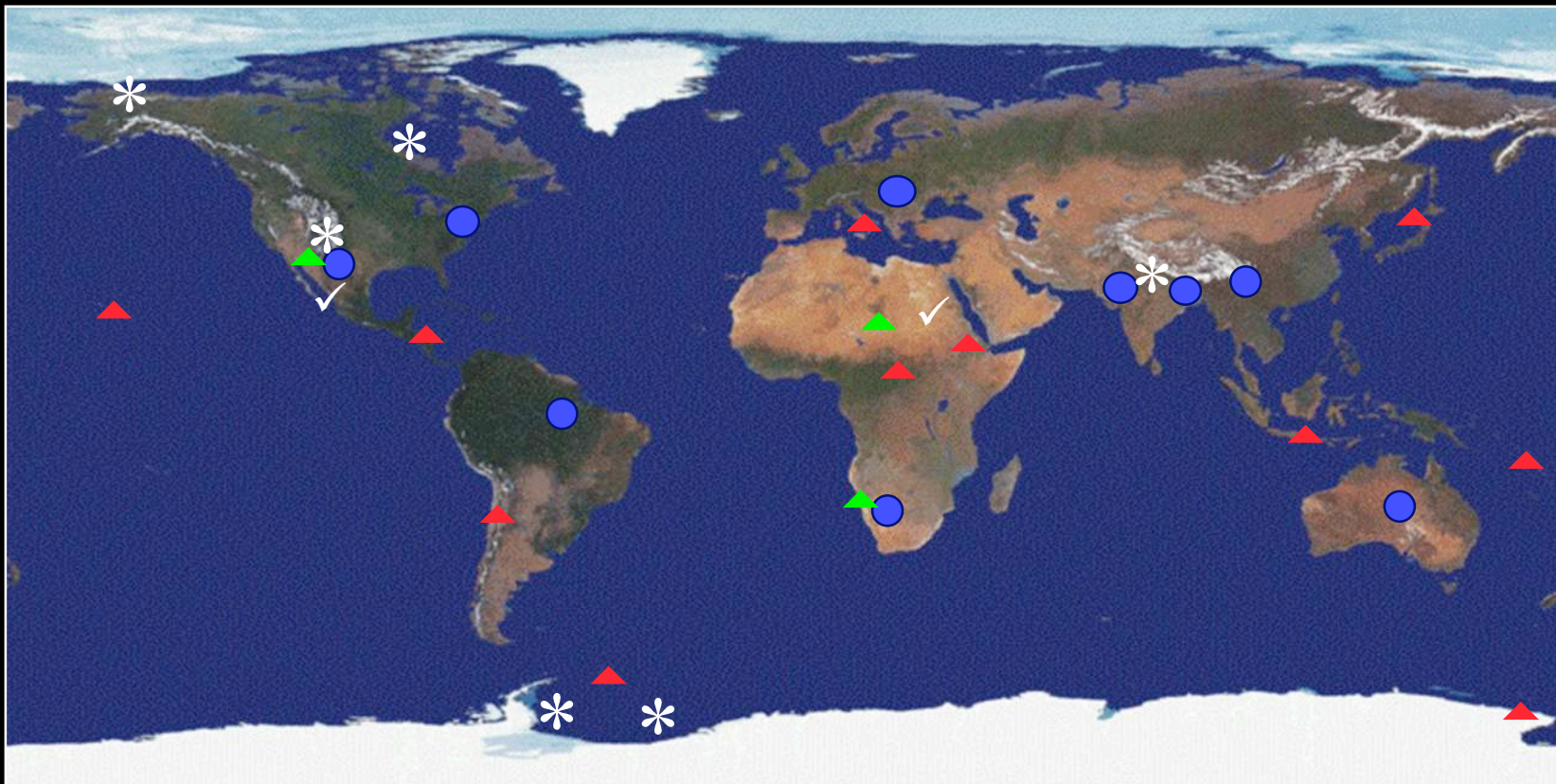
Classifier Output:
Water is blue, Land is Green



ESTC June 2004



ASE Targets: 2003-2004



- ▲ = volcanoes
- ▲ = dunes
- ✓ = aeolian

- * = ice formation/breakup
- = flooding



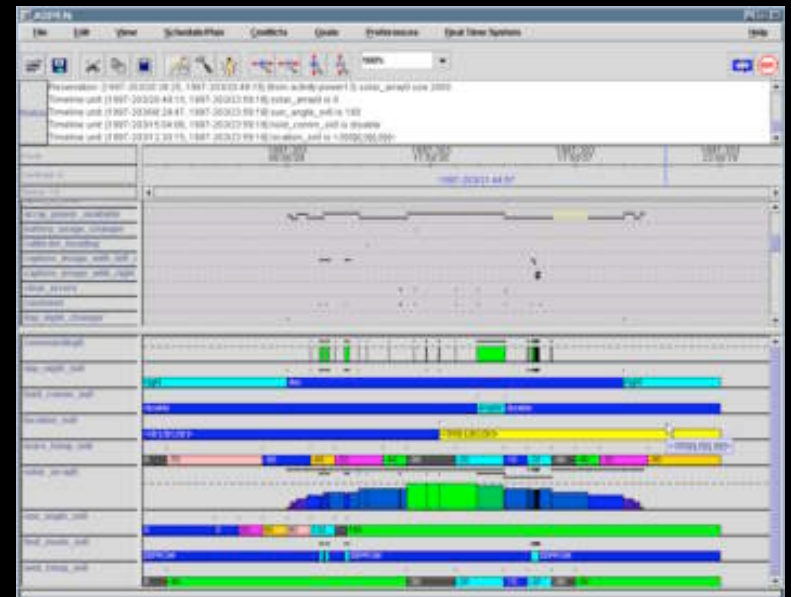
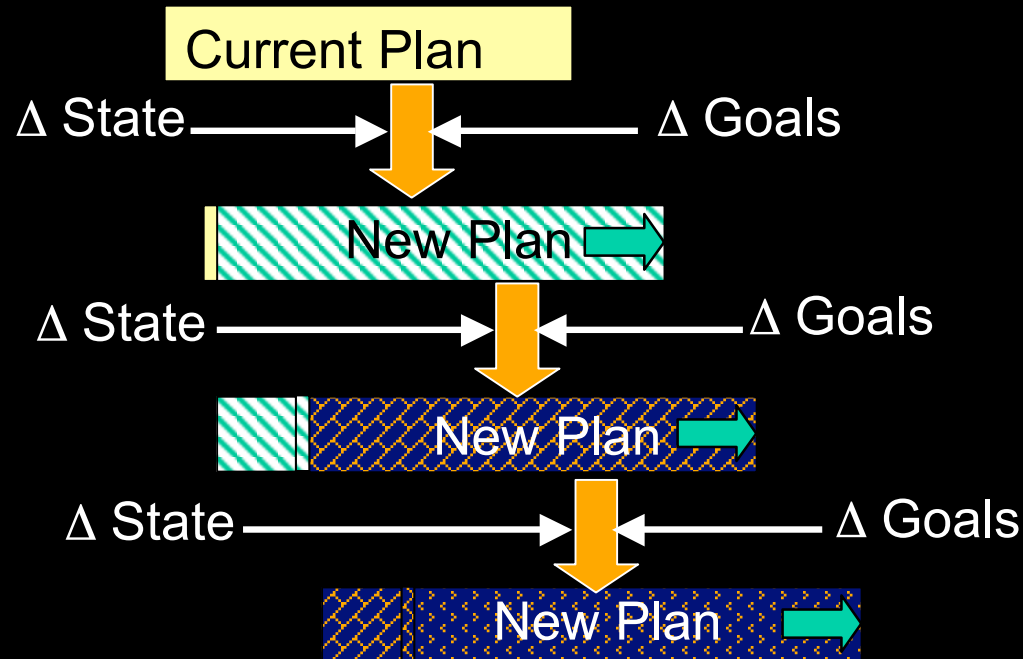
Autonomous Planning

- CASPER is the Continuous Activity Scheduling Planning Execution & Replanning software
- CASPER use a model of spacecraft activities to construct a mission plan to achieve mission goals while respecting spacecraft operations constraints
 - Example goals: science requests, downlink requests, maneuver requests
 - Example constraints: memory, power, propellant, etc.
- CASPER uses continuous planning techniques to achieve a quick response time
- Replanning
 - CASPER is used onboard to replan newly derived science goals



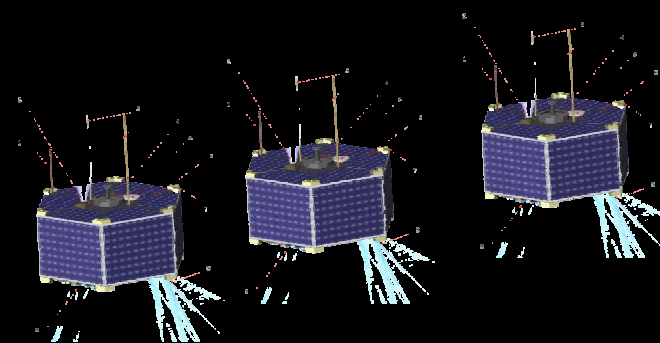
Onboard Replanning

- CASPER uses continuous planning techniques to achieve a quick response time



Other CASPER Deployments

- Also being applied to
 - Autonomous rover control (Rocky7, Rocky8)
 - Ground communications station control (CLEaR)
- Also being used as single agent in Teamwork/Coordination (rover & spacecraft)
- Three Corner Sat Mission
 - Launch Fall 2004





Autonomous Execution

- Uses Spacecraft Command Language (SCL) developed by Interface and Control Systems
- SCL integrates procedural programming with a forward-chaining, rule-based system for event-driven real-time processing
- In the ASE concept, SCL scripts are planned and scheduled by the CASPER onboard planner
- SCL to also be used in ground control of EO1
- SCL is a mature software product used on many mission including several flights: Clementine I, ROMPS, DATA-CHASER, ICM for ISS, FUSE,...

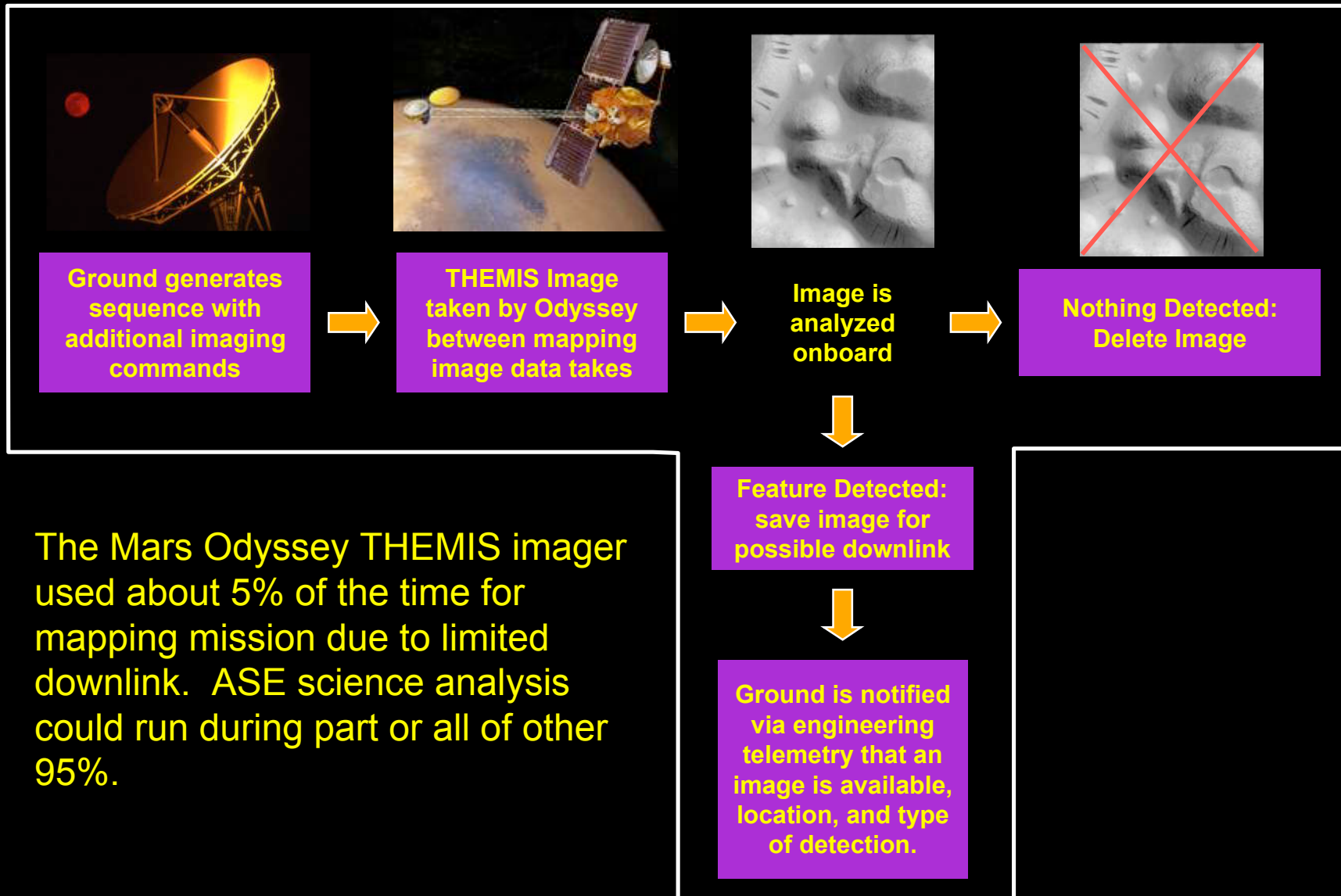




Possible Future Applications: Mars



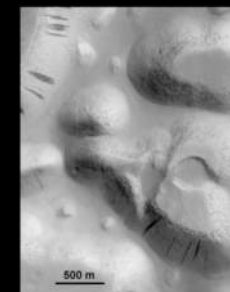
(Proposed Mars Odyssey Mission Scenario)



Mars Technology Infusion

- We are developing and testing general science algorithms for Mars missions using Mars Odyssey mission data
- Our goal is infusion on Mars Odyssey extended mission and a roadmap for Mars missions

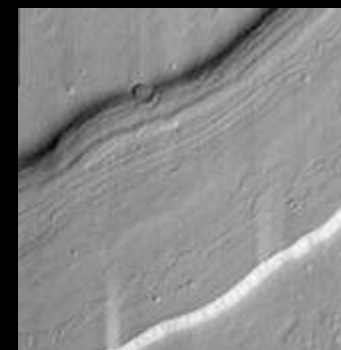
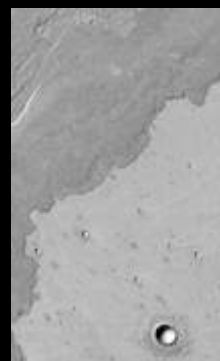
- Dark slope streaks



- Impact craters; faults/fractures; depressions (e.g., pit crater chains)



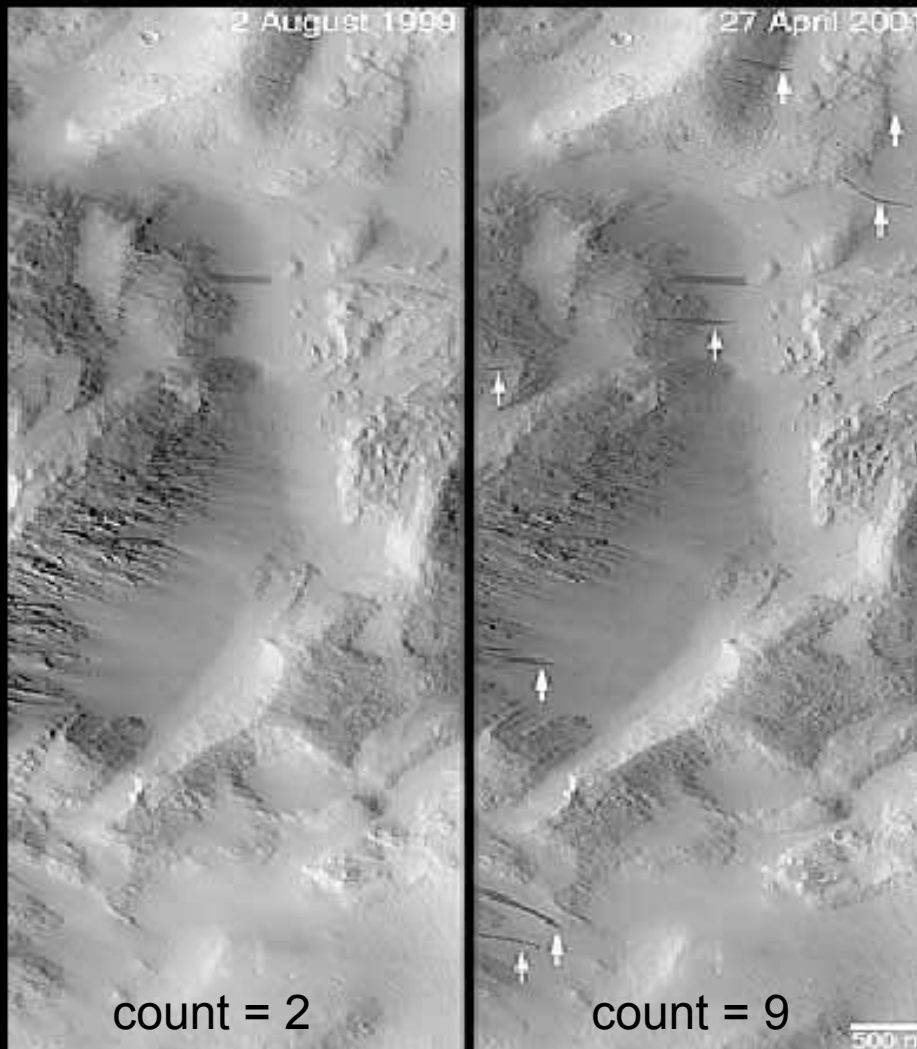
- Lava flows; ice-enriched flows (e.g., rock/ice glaciers)





Feature-based Change Detection

Dark Slope Streaks



After cataloging the number of dark slope streaks in an area of interest, a new image of the same area could be used to determine if new dark slope streaks have occurred. If so, the software could:

- Save image for downlink
- Save portions around selected features
- Output summary of features detected in engineering telemetry (count, location & size, etc.)

MGS MOC Release No. MOC2-284, 24 May 2001
courtesy of Malin Space Science Systems

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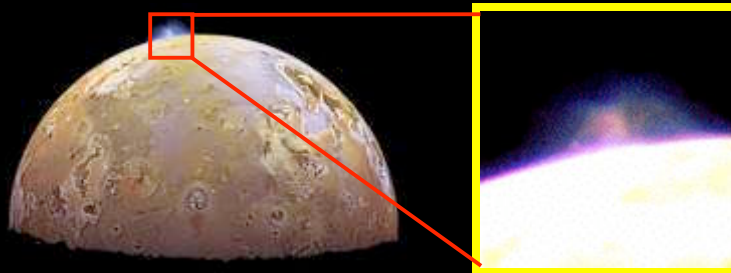




Possible Future Applications: Io

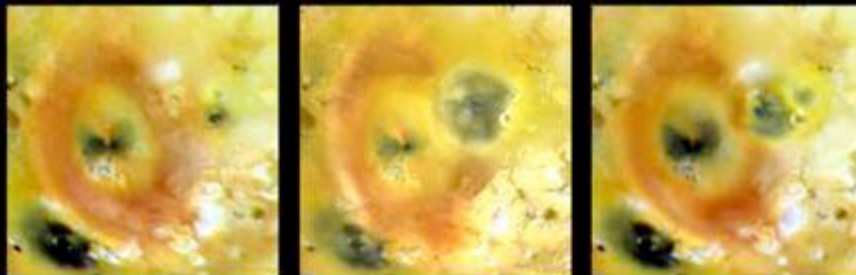


Feature identification: Volcanic plume detection



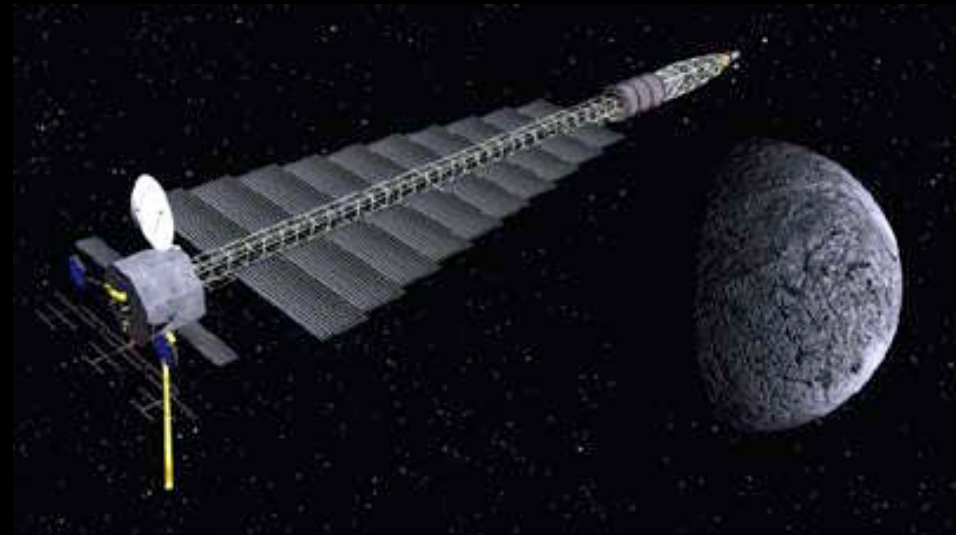
Masubi

Change detection: Emplacement of pyroclastics and lava flows at Io (Galileo data)



Pele and Pillan Patera, 1997-1999

JPL's proposed **JIMO** mission:
Jupiter Icy Moons Orbiter



High spectral, spatial and temporal monitoring of Jupiter and the Galilean satellites will be possible with JIMO





ASE Status

- Demonstrated complete loop: generate plan, collect data, analyze data, trigger new request, re-generate plan
- Achieved 100% of full success criteria:
 - 5 triggered data collects
 - 5 triggered data edits (actually commanded noop)
- Completed more than 20 data collects under ASE control
- Modeled most of the EO-1 spacecraft commands, constraints, etc.
 - Can schedule a typical week of operations (testing this soon)
 - Not scheduling infrequent tasks (some instrument calibrations and maintenance activities)... yet
- Unintentionally demonstrated anomaly recovery:
 - An activity failure triggered both a short-term SCL response and long-term CASPER re-planning



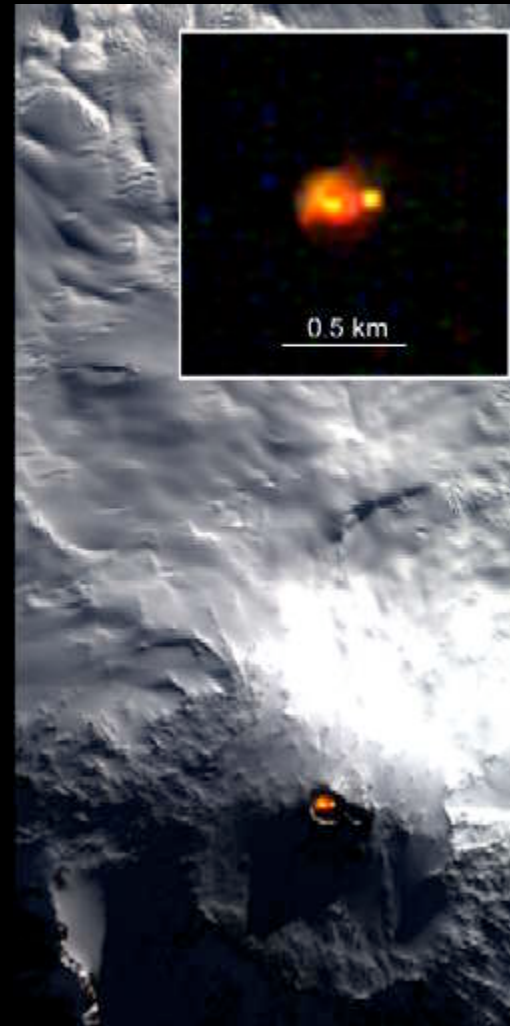


ASE Example

JPL

Mt. Erebus 13:46 UTC May 14, 2004

Response re-imaging was
on the next overflight
(6 _ hours later)!



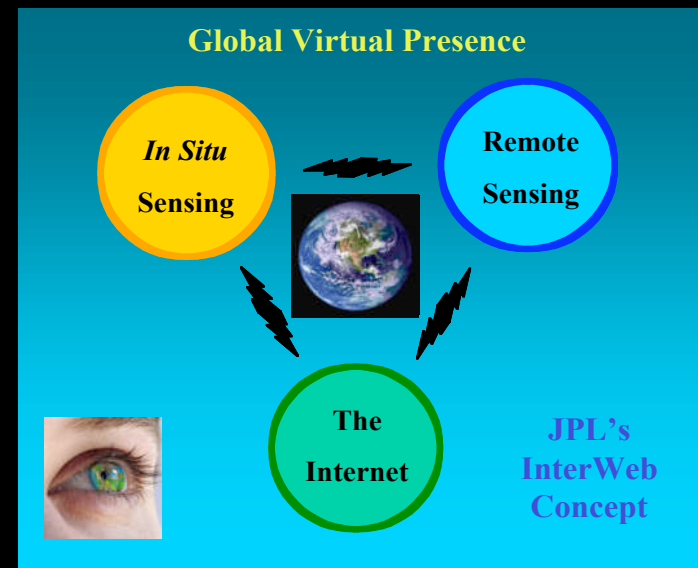
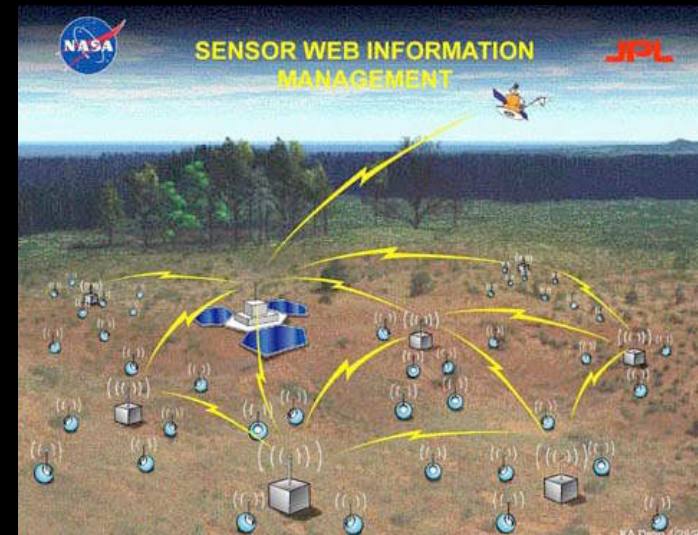
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Related Work: Sensor Webs

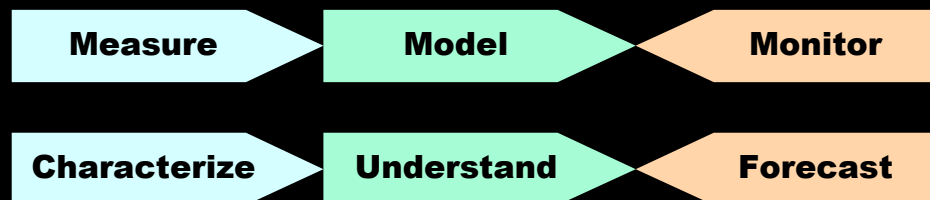
- Definition:
 - A networked set of instruments
 - Information is shared between sensors
 - Sensors automatically modify their behavior on the basis of the collected data

- Goal:
 - To monitor remote environments, hazards and disasters, and natural resources using new data acquisition strategies and systems for *integrated Earth sensing*



Sensor Web Benefits

- Benefits:
 - Increased science understanding and quicker disaster response as a result of automatically reallocating sensor assets during dynamic events such as flooding, volcanoes, earthquakes, fires, etc.
 - Allows scientists to specify multiple spatial resolutions by triggering additional sensors
 - Allows a continuous presence without operations staffing
 - Allows capture of non-periodic events





Timely Satellite Data

- Recent advances have made large amounts of timely satellite data readily available (see table)
- Unfortunately, for some applications higher resolution data or alternative instrumentation is needed to study science phenomena
- Ideally high resolution data would be continuously available
- Unfortunately, typically high resolution assets must be pointed at specific targets, or have infrequent over-flights (e.g., Landsat-7)

| Satellite | Instrument | Frequency of Overflight | Timeliness |
|-------------|---------------------|--------------------------------------|--|
| Terra, Aqua | MODIS | 12 hours daylight, 12 hours night | several hours from acquisition (DAAC); regional near real-time (DB) |
| QuikSCAT | Scatterometer radar | ~12 hours | daily |
| NOAA-POES | AVHRR | Variable, frequent | < 1 hour |
| GOES | Infra-Red, visible | Continuous | ~25 minutes |



EO-1 Sensorweb Experiments

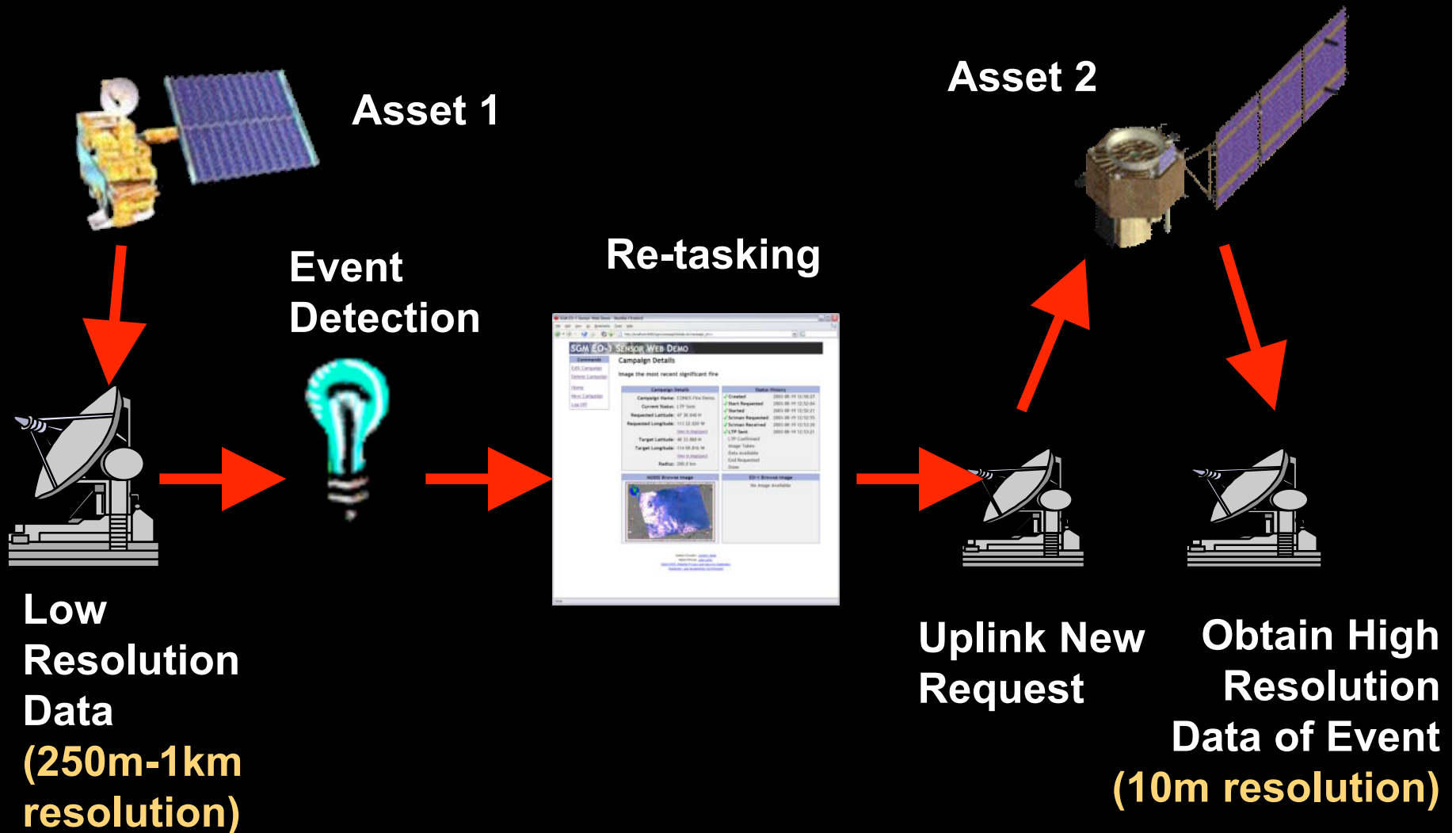


- In our application we use low resolution, high coverage sensors (Terra/Aqua, GOES) to trigger observations by high resolution instruments (EO-1)
- We have conducted *preliminary* experiments in demonstrating the Sensor Web concept to track
 - Wildfires,
 - Volcanos, and
 - Floods





Sensor Web Concept







Future Work: Sensor Webs

- The New Millennium Program has recently agreed to fund a sensor web observation campaign to study the worlds 250 most active volcanoes over the next several months
 - The campaign will utilize EO-1, Terra, Aqua, GOES, AVHRR, TOMS, and several ground assets
- This demonstration will provide important volcano science benefits:
 - More eruptions observed
 - Increased temporal resolution (especially soon after onset)
 - Multiple instruments tasked to observe events





Summary/Conclusions

- Using on-board autonomy software for planning, science data analysis, and execution will increase mission value and reduce mission cost by:
 - Returning only the most important science data
 - Allowing quick response to opportunistic and dynamic science events
- Using sensor web technology allows better use of observation assets for integrated global Earth science data collection





Acknowledgements

- Web Site: <http://ase.jpl.nasa.gov>
- ASE Team:

| | | |
|--|--|--|
| JPL: Rebecca Castano Steve Chien Ben Cichy Ashley Davies Russell Knight Gregg Rabideau Joe Roden Steve Schaffer Rob Sherwood Nghia Tang Danny Tran | ICS: Dan Arpin Darrell Boyer Jim VanGassbeck Univ. of Arizona: Vic Baker James Dohm Arizona State Univ. Ron Greeley Thomas Doggett Trinity Univ. Rachel Lee Honeywell: Glenn Bock Robert Bote Joe Howard | GSFC: Stuart Frye (Mitretek) Dan Mandl Lawrence Ong Seth Shulman Stephen Ungar Microtel: Jerry Hengemihle Nick Hengemihle Bruce Trout Scott Walling Hammers Eng.: Jeff D'Agostino |
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